Renewable and Sustainable Energy Reviews 16 (2012) 2545–2557

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Geoenergy in Poland

Bartłomiej Igliński*, Roman Buczkowski, Wojciech Kujawski, Marcin Cichosz, Grzegorz Piechota

*Nicolaus Copernicus University, Gagarina 7, 87-100 Toruń, Poland*

ARTICLE INFO

*Article history:*
Received 22 June 2011
Accepted 29 January 2012
Available online 20 March 2012

*Keywords:*
Renewable energy
Geoenergy
Balneology
Heat pumps
Poland

ABSTRACT

This paper presents the current state of geothermal energy production in Poland and its future development prospects. At present, there are four geothermal heating plants in Poland. In addition, warm water is used in seven spa towns in balneology as well as in seven thermal swimming pools for recreational purposes. There has recently been an increase in the number of installed heat pumps in Poland – reaching 10,000 in 2010. In the near future the development of geothermics in Poland is forecast to continue. The first power and heat geothermal plant is being built in Uniejów whilst in more than ten other towns special swimming pool complexes using geothermal warm water are being built or designed. In the coming years heat pumps will be installed in living and office buildings as well as in public use buildings (mostly in newly built ones). Moreover, in Poland it is planned to use heat pumps in order to recover waste heat from factories and power plants.



**Contents**

1. Introduction ..... 2546
2. Geothermal resources in Poland ..... 2546
3. The geothermal heat plants in Poland ..... 2546
   3.1. Bańska Niżna ..... 2546
   3.2. Mszczonów ..... 2547
   3.3. Pyrzyce ..... 2547
   3.4. Uniejów ..... 2549
   3.5. Economic and ecological effects ..... 2549
4. The use of geothermal water for balneological and recreational purposes in Poland ..... 2550
   4.1. Spa towns using geothermal water in Poland ..... 2550
      4.1.1. Ciechocinek ..... 2550
      4.1.2. Cieplice Śląskie Zdrój ..... 2551
      4.1.3. Duszniki Zdrój ..... 2551
      4.1.4. Iwonicz Zdrój ..... 2551
      4.1.5. Konstancin ..... 2551
      4.1.6. Lądek Zdrój ..... 2551
      4.1.7. Ustroń ..... 2551
   4.2. The use of geothermal waters for recreational purposes ..... 2552
      4.2.1. Bukowina Tatrzańska ..... 2552
      4.2.2. Grudziądz ..... 2552
      4.2.3. Mszczonów ..... 2552
      4.2.4. Uniejów ..... 2553
      4.2.5. Szaflary ..... 2553
      4.2.6. Zakopane (the Aquapark in Zakopane) ..... 2553
      4.2.7. Zakopane (Polana Szymoszkowa) ..... 2553

* Corresponding author. Tel.: +48 56 611 4331; fax: +48 56 654 24 77.
*E-mail address:* iglinski@chem.umk.pl (B. Igliński).

1364-0321/$ – see front matter 
doi:10.1016/j.rser.2012.01.062

5. Heat pumps in Poland ... 2553
5.1. Heat pumps in Poland – the analysis of surveys ... 2553
5.1.1. Analysis of the surveys “Heat Pumps in Poland – Producers” ... 2553
5.1.2. Analysis of the surveys “Heat Pumps in Poland – Customers” ... 2554
6. Future prospects for the development of geothermal energy in Poland ... 2555
7. Summary ... 2556
Acknowledgements ... 2556
References ... 2556

## 1. Introduction

According to Directive 2001/77/EC [1] and Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 [2], Poland is obliged to increase its use of energy from renewable sources. The target for renewable energy production in Poland is set to rise from $S_{2005}$ = 7.2% in 2005 to $S_{2020}$ = 15% in 2020.

Since 2000 a gradual increase in the amount of renewable energy has been observed (Fig. 1) [3,4]. In 2009, 253,153 TJ was obtained from renewable energy sources, which is 9.0% of primary energy in total [4].

The highest contribution to renewable energy production in 2009 was from solid biomass energy, which was 85.7% of the total renewable energy production. The next highest contribution to renewable energy production were:

- liquid biofuels – 7.1%,
- hydropower – 3.4%,
- biogas – 1.6%,
- wind – 1.5%,
- heat pumps – 0.4%,
- geothermal energy – 0.3% [4].

In Poland in 2010 about 10,000 heat pumps were installed and the amount of heat produced using these installations exceeded 1 PJ/year [5]. The data presented in Fig. 2 illustrate a constant increase in energy obtained from the Earth’s interior, especially in energy obtained using heat pumps [3–5].

This paper presents the results of sociometric research describing the current state of the renewable energy sector in Poland and its future development prospects in relation to geothermal energy. For the purpose of the research, the following surveys were carried out: “Heat Pumps in Poland – Producers” [6], “Heat Pumps in Poland – Customers” [7], the data obtained directly from geoenergy producers were also used.

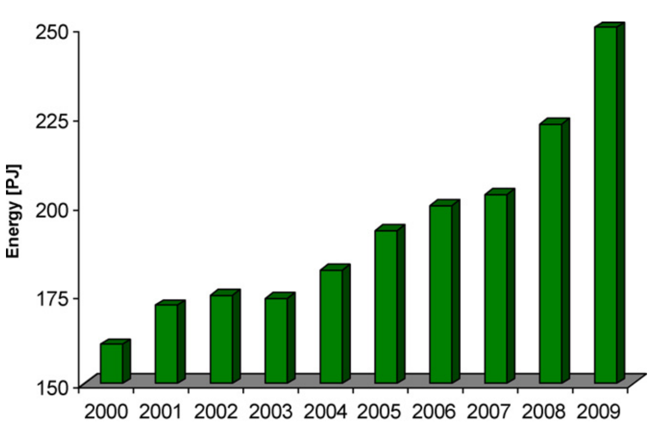


**Fig. 1.** Renewable energy production in Poland in 2000–2009 (own data based on Refs. [3,4]).

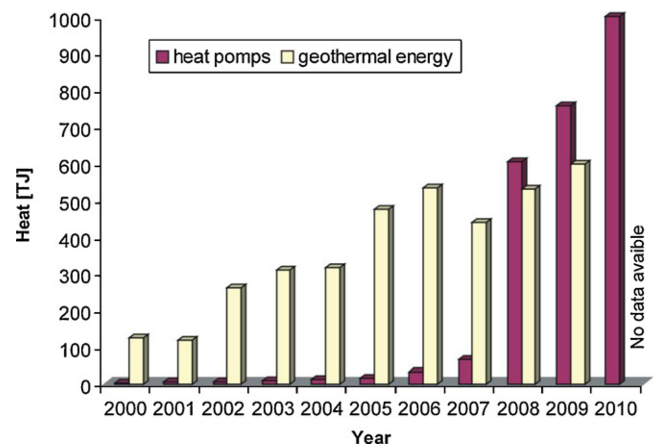


**Fig. 2.** Heat production using heat pumps and geothermal energy in Poland in years 2000–2009 (own data based on Refs. [3–5]).

This research is a continuation of an earlier work conducted in 2008, when surveys were sent out to renewable energy producers in Kujawsko-Pomorskie Voivodeship [8] and the work conducted in 2009, when the surveys were sent out to bioenergy producers in Poland [9].

## 2. Geothermal resources in Poland

In Poland, geothermal waters occurring in reservoirs located up to a depth of 3000 m, generally have a temperature not exceeding 100 °C [10–14]. The geothermal gradient is highly differentiated in Poland, depending on geological composition and, in particular, on halokinetic structures, which are characterised by high heat conductivity. Within the depth range of 200–2500 m, it varies from 20 to 110 m/1 °C. In the north-east part of the country the value of the thermal gradient increases to about 100 m/1 °C, which is related to a crystalline base occurring relatively shallow. The lowest values, of 20 m/1 °C, are present in the Sudety (Cieplice Śląskie-Zdrój, Lądek-Zdrój) [12–16].

About 2/3 of Poland’s area is thought to show good prospects in terms of exploiting geothermal potential using current technological capabilities (Fig. 3) [12–16].

## 3. The geothermal heat plants in Poland

In the middle of the 1980s research and development work was commenced to use geothermal energy in the heating sector: space heating and, on a semi-industrial scale, in agriculture and fish breeding. As a result, geothermal heat plants were opened in Bańska Niżna, Pyrzyce, Uniejów, Mszczonów (Fig. 4) and Stargard Szczeciński. Currently (May 2011), the plant in Stargard Szczeciński is not working due to economic problems [17].

### 3.1. Bańska Niżna

A warm source in the vicinity of Zakopane was already known in the 19th century, with water of temperature 20 °C being used in

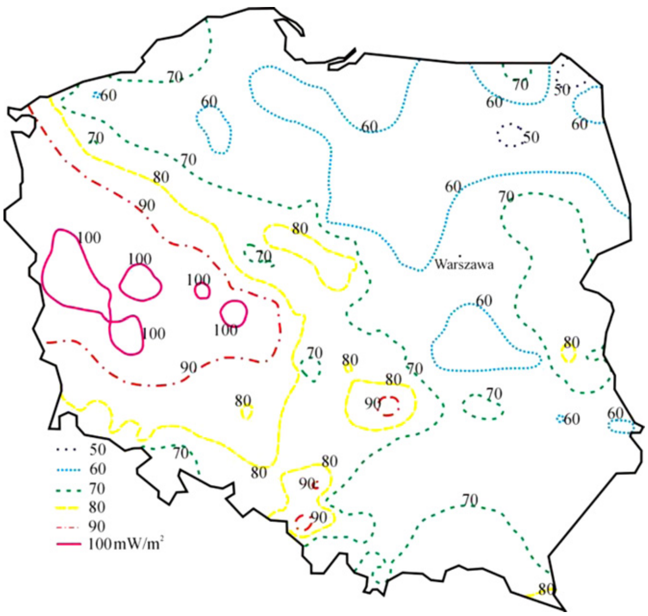


**Fig. 3.** The map of the terrestrial heat stream density for Poland, according to Ref. [15].

a swimming pool [18]. The first deep exploration well was created in Zakopane in 1963 and between 1970 and 1980 a few more bore-holes were drilled close to the Tatra Mountains.

It was a real breakthrough for the development of geothermics in Podhale when in 1981 the well Bańska-IG1 of final depth of 5263 m was drilled. The intensity of the artesian flow was 60 $m^3$/h, water temperature was 72 °C, general mineralisation was 3 g/$dm^3$ and static well pressure was 2.7 MPa [19].

In 2001 the construction of Bańska Niżna-Zakopane heating conduit was completed and a geothermal heating plant was opened in Bańska Niżna, due to which the last coke-fed boiler room in Zakopane was closed. It was also in 2001 that the construction of the Aquapark in Zakopane was commenced, whilst in 2004 the delivery of heating to the first open swimming pool in Szymoszkowa Polana was started [20,21]. Table 1 presents the most important data on geothermal bore-holes exploited to meet the heating needs of Podhale [18].


**Fig. 4.** The geothermal heat plants in Poland (May 2011).

**Fig. 5.** The well Bańska IG-1 (photography: B. Igliński).

The waters taken from the wells Bańska PGP-1 and Bańska IG-1 (Fig. 5) are classified as sulphate–chloride–sodium–calcium water type. The thermal waters are carried to the surface without using any pumps and are then directed to plate heat exchangers. In these heat exchangers the thermal water transfers its heat on to the network water, which is located in an independent circuit. Cooled thermal water is transported via a pipeline to the pump station where it is pumped to the aquifer (Fig. 6). The estimated power of this geothermal source is 15.5 $MW_t$ [20–23].

The geothermal source is topped up by a peak load source, which consists of two gas boilers with economisers (each of power of 10 $MW_t$), a gas–oil boiler of power of 15 $MW_t$ as well as three cogeneration gas aggregates of combined power of 2.1 $MW_t$. The total power of the peak load source is 37.1 $MW_t$ [19–22].

### 3.2. *Mszczonów*

Geothermics Mszczonów is unique on a world scale because the thermal water, after being used for energy purposes, is transported to the water supply system as drinking water. The thermal water is exploited from a bore-hole by means of a pump aggregate. The total power installed in Mszczonów heat plant is 7.4 $MW_t$, which includes a geothermal power source of 1.1 $MW_t$, an absorption heat pump of power 2.7 $MW_t$ and gas boilers of power 3.6 $MW_t$ [11,24].

The thermal water is classified as hydrogencarbonate–chloride–sodium–calcium water type and its mineralisation is at the level of 610 mg/$dm^3$; it also contains free carbon dioxide. The exploitation capacity, which is at the same time the amount of resources available for exploitation at the well Mszczonów IG-1 is 60 $m^3$/h [11,24].

### 3.3. *Pyrzyce*

In September 1992 in Pyrzyce plant design work was commenced and the drilling of three geothermal bore-holes took place. This was followed in the middle of 1993 by the implementation of the geothermal system, volume objects and a heating system network directed towards the town [25,26].

The heating system was constructed in 1992–1997 and includes:

- a geothermal-gas heat plan of peak power of 48 $MW_t$,
- a heating network of pre-insulated pipes (15 km),

**Table 1**
The most important data on geothermal bore-holes exploited for the heating purposes of Podhale [18].

| Name of bore-hole | Bańska IG-1 | Bańska PGP-1 | Biały Dunajec PAN-1 | Biały Dunajec PGP-2 |
|---|---|---|---|---|
| Time of construction | 1979–1981 | 1997 | 1989 | 1997–1998 |
| The year exploitation commenced | 1992 | 2001 | 1992 | 2001 |
| The purpose of bore-hole in the system | Production | Production | Absorption | Absorption |
| Total depth [m] | 5261 | 3242 | 2394 | 2450 |
| Reservoir rock lithology | Carbonate conglomerates, limestone, dolomite | | | |
| Maximum output [$m^3$/h] | 120 | 550 | – | – |
| Water temperature [°C] | 82 | 87 | – | – |
| Well pressure [MPa] | 2.6 (static) | 2.7 (static) | 5.5–6.0 (forcing) | |
| General mineralisation [g/$dm^3$] | 2.5 | 2.7 | – | – |
| Maximum absorbability [$m^3$/h] | – | – | 200 | 400 |

- a controlling and signalling network (28 km),
- 66 thermal centres (fully automated).

The investment cost was 60.6 million PLN. The geothermal heat plant consists of three major parts: a geothermal water circuit, a drinking water network circuit and a high temperature circuit (Fig. 7) [25,26].

The depth of the geothermal wells is approximately 1620 m, whilst the mean water temperature in the bed is about 64 °C. The static level of the well water table becomes stabilised at a depth of 34 m below the ground. Geothermal water is exploited by means of multi-gradient deep-well pumps installed at a depth of 110 m [27]. The pumps are powered by a voltage of 2 kV and controlled by frequency converters which adapt the pump's efficiency to meet the current heat demand (90–170 $m^3$/h from one bore-hole). The exploited geothermal water of 61 °C temperature and after passing through filters, is directed to a first-degree exchanger, where it gives up its heat to the network water returning from the town.

In the heat exchanger the network water is heated up, depending on conditions, from 40 to 60 °C. The total heat capacity of an exchanger at a flow time is 7.2 $MW_t$. In order to optimise the use of heat energy from geothermal water, the water is directed to a second-degree exchanger, where it is cooled down to a temperature of 26 °C. This is possible because a part of the returning network water was previously cooled down in an absorption heat pump evaporator. After leaving the second exchanger, the geothermal water is then transported through the second battery of filters and is pumped back to the very same geological layer from which it was exploited. The pumping wells are located about 1.5 km from the production wells [25–27].

Geothermal water is characterised by strong mineralisation and salinity – about 120 g/$dm^3$ which, in contact with oxygen, makes it a corrosive fluid. Consequently, casing pipes for geothermal wells

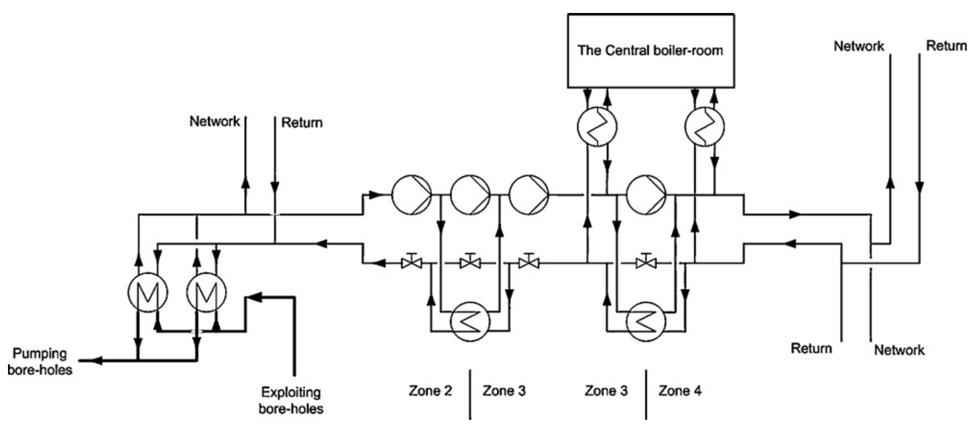


**Fig. 6.** A diagram of the geothermal system in Bańska Niżna [20–23].

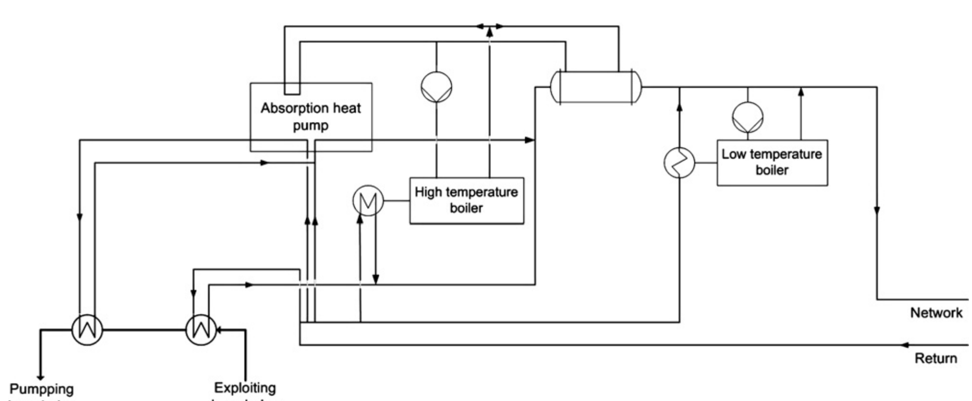


**Fig. 7.** A diagram of the geothermal system in Pyrzyce [25,26].

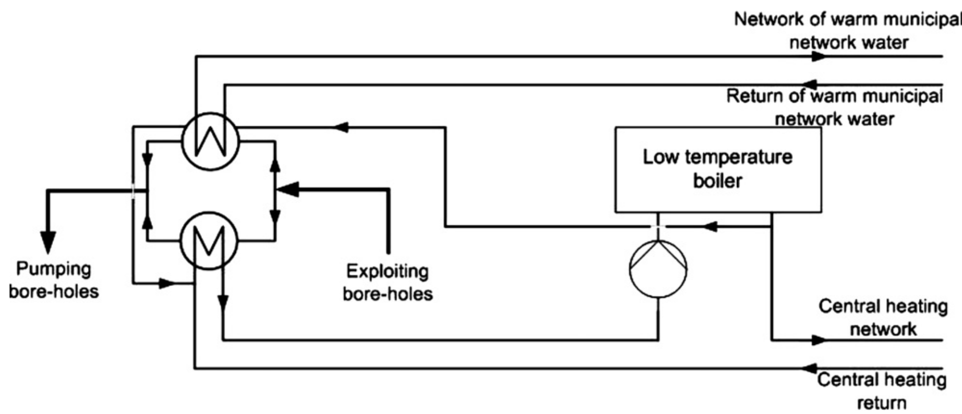


**Fig. 8.** A diagram of the geothermal system in Uniejów [28,29].

are made with an anticorrosive agent, which guarantees 30 years of operation. The exchanger plates are made wholly from titanium whilst the transmission pipelines are made of carbon steel with a low content of sulphur and phosphorus (<0.02%).

When the deep-well pumps are stopped, nitrogen is pumped into the whole geothermal circuit in order to create a nitrogen "cushion", which prevents air from entering the pipeline, and therefore, reduces the risk of corrosion [25–27].

### *3.4. Uniejów*

In 1978 a company looking for oil and natural gas came across hot springs in Uniejów. At this time, the Polish Geological Institute created a hydro-geological bore-hole, IGH-1. In 1990–1991 two new geothermal bore-holes PIG/AGH-1 and PIG/AGH-2 were created. In 1999 the Voivodeship Fund for Environmental Protection and Water Management in Łódź as well as Uniejów Municipality set up a limited company "Geotermia Uniejów" [28,29].

One of the most important uses of the geothermal water, which is exploited by "Geotermia Uniejów" company, is to provide heating for the town. The new geothermal system has replaced 10 local coal-fired boilers as well as 160 boilers in houses. The boiler system consists of two parts. The first is a geothermal block and the second is a "biomass" block which consists of two boilers fed with wood chippings (an "oil" block was previously used). This block is used for heating the network water up to the right temperature during peak heating power demand [28,29].

The source from which hot water is exploited in Uniejów has artesian conditions and the artesian flow pressure reaches 0.26 MPa. The exploitation of thermal water and heat recovery takes place in a closed circuit. After passing through a filtering system, underground water passes to a set of five pumps of total capacity of 120 $m^3$/h. Next, it is pumped to the central heating and municipal network warm water exchangers. After giving up its heat in the exchangers, the exploited water is cooled to temperatures of 40–45 °C and directed through absorbing bore-holes PIG/AGH-1 and IGH-1 to the same aquifer (Fig. 8) [28,29].

The heat distribution system consists of a network of pipelines made from pre-insulated steel pipes with a total length of 10 km. It is equipped with individual measuring devices and valves. The geothermal heat production plant and associated heating network are controlled and monitored by an integrated computer system, which optimises effectiveness of work and reduces any energy loss. Two-third of Uniejów inhabitants benefit from geothermal heating. Apart from the individual customers, geothermics is also used by collective customers such as Termy Uniejów (Uniejów Thermal Pools), schools, kindergartens, office buildings and a sports hall [28,29].

### *3.5. Economic and ecological effects*

High expenditure is needed to cover the cost of the geothermal boiler infrastructure and its modernisation. It takes 10 years to pay for it. After that time, the remaining costs are far smaller as there is no need for coal or oil. The geothermal heat is almost for free. The initial high cost is linked to large expenditures that were spent on implementation of costly geothermal systems and modernisation of the remaining parts of the heating system, that is, the main line network, terminals to former boilers, and heat centres with automatic control [17].

For many years the net price for 1 GJ of geothermal heat has remained at a similar level (about 40 PLN/GJ), whilst the heat obtained from conventional sources has been getting more and more expensive (Fig. 9). At present, it is only the heat obtained from hard coal burning that is competitive in comparison to geothermal heat. However, if the full costs were to be considered (e.g. everyday service of a coal-fired furnace, maintenance, chimney cleaning, cost of kindling material, removal of ash etc.), it is clear that geothermics is the most economically profitable type of energy [21].

Heating powered from geothermal sources has many advantages, which are making geothermal heat increasingly popular in Poland. These include:

- a heat exchanger is a virtually maintenance-free device,
- no ventilation or chimney is required and a heat exchanger takes up little space,
- the latest evidence shows that there is a high degree of safety associated with geothermal heating systems and they are virtually breakdown-free,

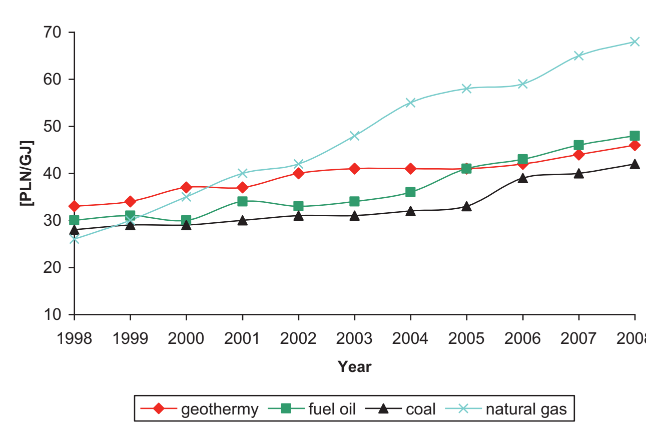


**Fig. 9.** The comparison of net prices for individual customers per 1 GJ for different energy sources (Geotermia Podhale) [21].

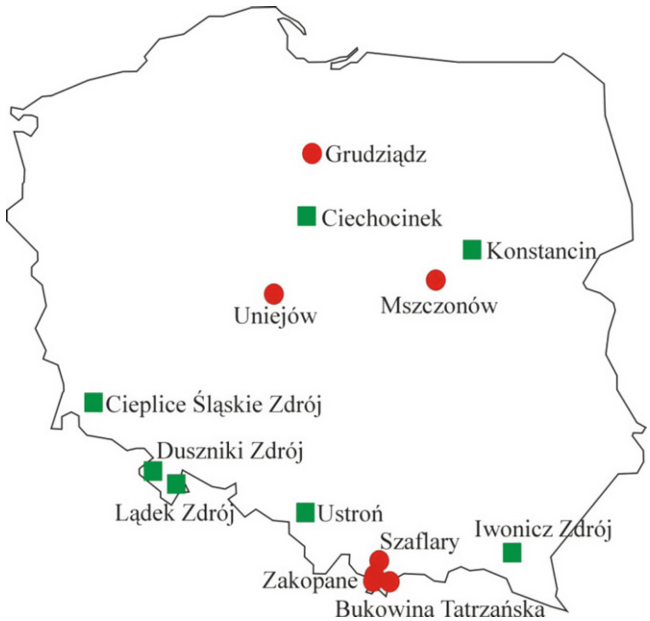


**Fig. 10.** Spa towns (squares) and swimming pools (circles) using geothermal water in Poland (May 2011).

- the protection of environment – the implementation of a geothermal system leads to a considerable decrease in pollutant emissions ($CO_2$, $SO_2$, $NO_x$, dusts) [17,21].

In addition, it is worth noting that in Uniejów since the heating season 2006/2007, biomass furnaces have been used instead of oil furnaces. As a result, the inhabitants of Uniejów now use solely renewable energy [30].

## 4. The use of geothermal water for balneological and recreational purposes in Poland

Geothermal water has been used for balneological purposes in Poland over the last few centuries and, recently, thermal swimming pools have also been built [14,17]. Currently (May 2011), warm geothermal water is used in seven spa towns and in seven thermal swimming pools, which are located in central and southern Poland (Fig. 10).

### *4.1. Spa towns using geothermal water in Poland*

The tradition of using underground water for healing in Poland goes back as far as the 11th century, when the wife of king Władysław Herman cured her ailments with hot baths in Inowłódz upon Pilica. In 1281 the monks of the Order of St. John in Strzegom were given the right to use mineral water springs in Cieplice Śląskie Zdrój and Lądek Zdrój. A few years later the Cieplice Spa was opened and progressed to become a well-known European spa in the 16th century. Queen Maria Kazimiera, the wife of king Jan Sobieski, cured her ailments there in the 17th century. The turn of the 18th and 19th century initiated a trend of “going to the waters” that was to last for over a century, resulting in the continued development of spa infrastructure [31,32].

In the 20th century there was further interest in spa medical treatments. It was at that time that the Association of Polish Spas and the Polish Balneological Society were established. These institutions ensured that the development of spa medical treatments was of sufficient quality as well as ensuring a high standard of services offered [31,32].

**Fig. 11.** A graduation tower no. 3 in Ciechocinek (photography: B. Igliński).

According to the stipulations of the International Balneological Conference in Nauheim in 1911, underground water of temperature at least 20 °C at its outflow can be classed as medical thermal water in Poland [33]. A bath in water of temperature of 20–35 °C does not lead to any thermal effects, but when the water temperature is above 37 °C, the human body reacts by dilating blood vessels. In addition, metabolic processes are intensified and ion exchange between the skin and mineral components in water is increased. The medicinal properties of a mineral water bath are reinforced by the influence of certain components such as iodide ions, sulphide ions and carbon dioxide [33].

#### *4.1.1. Ciechocinek*

Ciechocinek is one of the most famous Polish spa towns. It was as early as the 13th century that in nearby Słońsk salt was obtained from evaporation of salt springs. After partition of Poland in 1772, when Austria had taken the salt mines in Wieliczka and Bochnia, it has been searching for exploitable sources of brine and was the largest discovered in Ciechocinek [34].

Between 1828 and 1859 three saline graduation towers were constructed (Fig. 11). Currently, warm brine is transported to the top part of a graduation tower (a wind turbine was previously used for this purpose) from the source “Grzybek” (“Little Mushroom” in Polish). Next, the water flows by the force of gravity down the graduation tower walls. The towers are filled with blackthorn twigs. The brine flowing through blackthorn is evaporated and its concentration increases from 5.8 to 27%. After passing through the graduation towers, the brine is transported to the saline leads, where its concentration is further increased at a high temperature (95–104 °C). This is the method of crystallising salt (NaCl), which, after leaving the leads, is dried and sold for consumption. The solution left after salt has been taken away is known as an end liquor and the Ciechocinek sludge. The sludge is a sediment that remains at the bottom of the saline leads after both the salt and liquor have been removed. The sludge and the end liquor are used in medical baths [35,36].

In 1836 the first complex with bath tubes for saline baths was set up. As a result of the spa’s development, new mineral water springs were searched for and opened for exploitation. A part of exploitation included providing water classed as suitable for drinking. Thus, a mineral water bottling plant – Krystynka – was set up in Ciechocinek (water is bottled without any additional chemical conditioning) [35,36].

The first thermal water spring of temperature 27 °C was opened for exploitation in 1932. According to the balneological

**Table 2**
Description of working mineral spring intakes in Ciechocinek [35,36].

| No. | Depth [m] | Year of opening | Temperature [°C] | General mineralisation [mg/dm$^3$] | Application |
|---|---|---|---|---|---|
| 1. | 414.5 | 1911 | 18 | 58,020 | Graduation tower – saline works |
| 2. | 757/1305 | 1932 | 27 | 41,850 | Balneotherapy |
| 3. | 1378.1 | 1952 | 34.5 | 67,076 | Balneotherapy |
| 4. | 23.7 | 1961 | 11 | 9715 | Swimming pool |
| 5. | 22 | 1976 | 10.5 | 2273 | Swimming pool – water bottling plant |
| 6. | 22 | 1976 | 10.5 | 2184 | Swimming pool – water bottling plant |
| 7. | 1450/1821 | 1965 | 37 | 69,718 | Balneotherapy |
| 8. | 34 | 1976 | 12.0 | 3300 | Water bottling plant |

classification, the types of mineral water occurring in Ciechocinek are classified as chloride-sodium, bromide, iodide, sulphide, fluoride as well as thermal water (Table 2). When combined, these water types exert a healing influence on a patient undergoing baths, inhalation or the water drinking treatment. The range of ailments treated in Ciechocinek includes locomotory organs and rheumatic diseases, circulation and respiratory system diseases found both in children and adults [35,36].

#### 4.1.2. Cieplice Śląskie Zdrój

The thermal waters utilised in Cieplice Śląskie Zdrój belong to hyperthermal fluoride and silicon types [37]. The thermal water is obtained from shallow (4–5 m) bell-type intakes, well shafts (14–23 m) and bore-holes (37–160 m). Water of temperature of barely above 20 °C flows by force of gravity from a water intake to tanks from where it is pumped to swimming pools, bath tubs and for the water drinking treatment. Until the 1970s the water destined for bathing had to be heated up. This problem was solved by exploiting 63 °C water from the Cieplice-2 bore-hole (Table 3). This solution resulted in a boiler-room no longer being needed. The surplus of hot water is used for heating purposes, which greatly improved the economic situation of the spa [37–39].

#### 4.1.3. Duszniki Zdrój

A healing spring "Zimny Zdrój" ("Cold Spring" in Polish) was mentioned as early as the 15th century. In 1748 the first investigation of mineral water springs was carried out and in 1769 Duszniki became an official spa by listing "Zimny Zdrój" on the healing springs register of what was Prussia at that time [40–42].

The water from Duszniki springs has a temperature only just above 20 °C. A large amount of carbon dioxide decompresses during its outflow resulting in the cooling down of the water. In 2002 a bore-hole GT-1, 1695 m deep, was drilled and the following information was found:

- from 193.5 to 534 m the water has a temperature of 25.7 °C, its type is 0.35% thermal acidic water $HCO_3$–Na–Ca–Mg, Fe, Si, with flow capacity of 20 m$^3$/h,
- from 552.5 to 1695 m the water has a temperature of 34.7 °C, its type is 0.34% thermal acidic water $HCO_3$–Na–Ca–Mg, Fe, Si, with flow capacity of 30 m$^3$/h [40–42].

#### 4.1.4. Iwonicz Zdrój

The spa Iwonicz Zdrój uses brines of temperature 20 °C and high mineralisation (6–19 g/dm$^3$), abundant in bromine, iodine and free carbon dioxide [43,44]. At the beginning of the 20th century a few bore-holes were drilled up to the depth of 400 m, due to which thermal water is still being used in Iwonicz Zdrój [32].

#### 4.1.5. Konstancin

Konstancin uses thermal chlorine–sodium, bromide, iodide and ferruginous types of water of temperature of 29 °C and of brine concentration 6.49%. The ailments treated in the spa include conditions following stroke and brain injuries, semi-paresis, conditions following heart-stroke, congenial defects of the osseous and muscular system, and diseases of the lower and upper respiratory system. In 2011 it is planned to construct a hydrotherapy centre (including brine swimming pools and a physiotherapy centre), which is to be known as the Hydrotherapy Centre in Konstancin-Jeziorna [45].

#### 4.1.6. Lądek Zdrój

Lądek Zdrój is considered to be the oldest Polish spa town as, according to the historical sources, it was in 1241 that the existing bathing systems were destroyed by the Mongol troops returning from the battle of Legnica. At the beginning of the 20th century the Lądek springs were found to contain natural radon waters, which greatly increased the spa's popularity in medical circles [46].

The thermal water from Lądek Zdrój is used in balneological healing (treatments in bath tubs, swimming pools and showers) [42]. The thermal water is obtained from seven intakes of total capacity of 58 m$^3$/h. Half of the water of temperature of 20–28.5 °C is exploited from shallow intakes (up to 10 m), which were opened in the 19th century. The other half is hyperthermal water of temperature 45 °C obtained from a 700 m deep well "Zdzisław". Lądek water is classed as having mineralisation of 0.2 g/dm$^3$ and being a hydrogencarbonate, fluoride-sulphate, radon type [46].

#### 4.1.7. Ustroń

Ustroń was granted the status of a spa town at the end of the 19th century [11,47]. The four swimming pools of the Spa Physiotherapy Centre are filled with brine of concentration 3–4% and temperature 30 °C; kinesiotherapy exercises take place within these pools. Baths take place in water with dissolved carbon dioxide. These are

**Table 3**
Thermal spring intakes in Cieplice Śląskie Zdrój [38,39].

| The name of the spring | Type of intake | Number of intakes | Year of opening | Water temperature [°C] | Mineralisation [mg/dm$^3$] |
|---|---|---|---|---|---|
| Marysieńka | Well | 1 | 1880/82 | 21.7 | 550 |
| | Bore-hole | 1 | | | |
| Antoni-Wacław | Bell-type | 2 | 1910/11 | 19 | 510 |
| Sobieski | Bell-type | 1 | 1929/30 | 22.2 | 465 |
| Nowe | Bell-type | 4 | 1929/30 | 33.3 | 517 |
| | Bore-hole | 1 | | | |
| Basenowe Damskie | Bell-type | 2 | 1929/30 | 40.8 | 537 |
| Basenowe Męskie | Bell-type | 1 | 1929/30 | 39.7 | 538 |
| Cieplice-1 (C-1) | Bore-hole | 1 | 1971, depth increased in 1998 | 86.7 | – |
| Cieplice 2 (C-2) | Bore-hole | 1 | 1972 | 59.5 | 535 |

**Fig. 12.** The water slides in Bukowina Tatrzańska Thermal Swimming Pools (photography: B. Igliński).

especially beneficial when treating high blood pressure, sclerosis changes as well as during convalescence. $CO_2$, which is contained in the water, is released onto the skin in the form of gas bubbles and this instigates many changes in the human body by dilating artery and vein capillary vessels. This results in a lowering of blood pressure. Baths with $CO_2$ also have a calming and relaxing effect [11].

### *4.2. The use of geothermal waters for recreational purposes*

Every year there are more and more places in Poland where it is possible to use geothermal baths as a tourist. All centres offer warm brine and/or water heated by means of geothermal heat.

#### *4.2.1. Bukowina Tatrzańska*

In 2005 the Bukowina Tatrzańska well had its exploitation resources' quantity and temperature confirmed: quantity $Q = 40.0\,m^3$ and water temperature $t = 64.5\,°C$. Water obtained from an exploitation bore-hole, after giving up its heat in heat exchangers and swimming pools, is directed (after extra cooling) to a nearby stream, Poroniec [48,49].

"Bukowina Tatrzańska Thermal Swimming Pools" is one of the biggest and most modern sites in Europe; the total area of water surface is 1885 $m^2$ and the capacity of swimming pools is 2260 $m^3$. The thermal installation consists of six outdoor swimming pools as well as six indoor ones equipped with hydromassage systems. The complex includes:

- a swimming pool (water temperature of 28–30 °C),
- leisure pools (water temperature of 30–36 °C),
- hydromassage pools (water temperature of 30–36 °C),
- shallow pools (water temperature of 30–36 °C),
- a rock cave, slides of total length 100 m (Fig. 12) [48,49].

#### *4.2.2. Grudziądz*

In the area of Grudziądz the healing thermal waters were discovered by means of the bore-holes Grudziądz 2 and Grudziądz IG-1. At present, the brine obtained from the intake Grudziądz IG-1 is used for medical purposes. The well Grudziądz IG-1 was constructed in winter 1971/72 in a place called Marusza, located south-west of Grudziądz [50,51].

The bore-hole in Marusza was drilled to a depth of 3070 m. At the depth between 1630 and 1607 m (Lower Jurassic sediments) a brine reservoir was discovered. The artesian flow of brine reached a height greater than 13 m above the ground, its capacity was 35 $m^3$/h, its temperature was 44 °C and salinity was 8%. The results of chemical analyses suggest that the composition of thermal water is stable (Table 4). According to the chemical analyses carried out in 1972, 2002 and 2006, fluctuation of particular components is low and amounts to only a few per cent. The greatest difference was recorded for the amount of sulphate(VI) ions and iron. The increase in iron concentration which exceeds 10 mg/$dm^3$ means that this type of water is classed as medical ferruginous [50,51].

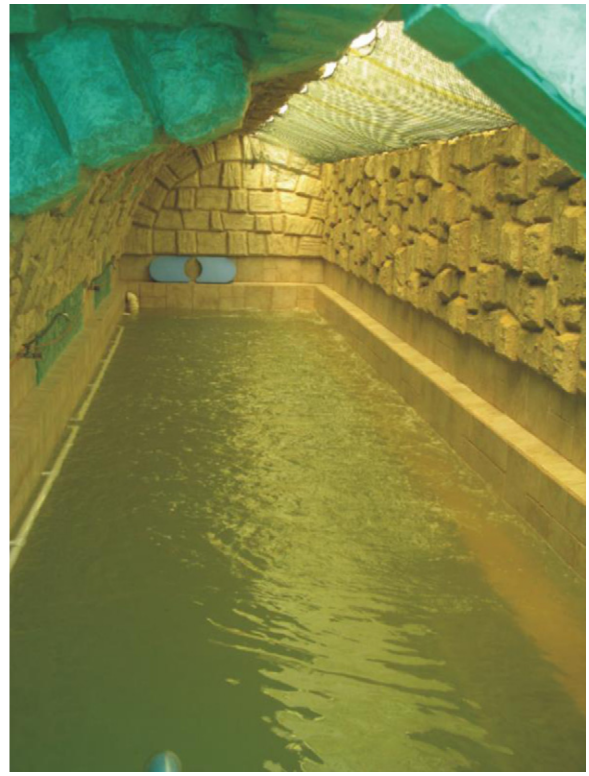

**Fig. 13.** The Brine Cave in Grudziądz (photography: B. Igliński).

In March 2006 the first amenity was built in Grudziądz; it was equipped with modern bath tubs, inhaler and cryotherapy facilities, a sports hall, an infrared sauna and two massage rooms. In May 2006 a pyramid with a brine graduation tower was opened, which facilitated group inhalation within an enclosed space as well as post-treatment relaxation in total silence. A graduation tower made of Chinese heather is enclosed in a pyramid building modelled on the Great Pyramid of Cheops in Egypt. In June 2006 the Brine Cave was made available, which made group baths and gymnastics in brine possible (Fig. 13) [50].

The following pools have been in use in Geotermia Grudziądz since 2007:

- the children's pool – salt concentration of 2% and temperature of 32 °C,
- the main pool – salt concentration of 3% and temperature of 32 °C,
- a pool with an artificial current – salt concentration of 3% and temperature of 32 °C,
- an outdoor pool – salt concentration of 7.9% and temperature of 30 °C [50].

#### *4.2.3. Mszczonów*

Mszczonów Thermal Pools, opened in June 2008, make use of geothermal waters from the Mining Institute of Geotermia Mazowiecka S.A. Two pool basins of depth of 1.2–1.3 m (including an indoor one) are linked by a canal and filled with unprocessed geothermal water of temperature of 32–34 °C. The leisure pool of

**Table 4**
Physico-chemical parameters of water from the well Grudziądz IG-1 [51].

| Date when an analysis was carried out | pH | TDS | $Na^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Fe_{tot}$ | $Cl^-$ | $SO_4{}^{2-}$ | $HCO_3{}^-$ | $I^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [mg/dm$^3$] | | | | | | | | | |
| 09.06.1972 | 6.0 | 77700 | 26000 | 2510 | 893 | 190 | 4.2 | 47020 | 440 | 202 | 3.4 |
| 20.02.2002 | 6.6 | 79400 | 26600 | 2557 | 899 | 198 | 12.5 | 47932 | 579 | 204 | 3.6 |
| 21.02.2006 | 7.6 | 79420 | 26900 | 2435 | 918 | 183 | 9.8 | 48212 | 547 | 183 | 2.8 |

depth of 1.2–1.4 m is equipped with a variety of attractive water features, which also contribute to recreation, such as an artificial river, wall massage, and neck massage [52].

#### 4.2.4. Uniejów

The Uniejów Thermal Pools using medical hot brine were opened in 2008. Currently, the town of Uniejów is in the process of applying for a spa status [53,54]. At the moment, the tourists have three pool basins at their disposal (the centre will be extended):

- a swimming pool basin with a temperature of 25–27 °C during summer period and 28–30 °C during winter,
- a brine basin with a temperature of 33 °C during the summer period and 36 °C during winter,
- a children's basin with a temperature of 30 °C during summer.

In the immediate vicinity of the Uniejów Thermal Pool complex there is a full-size football pitch where the turf is heated with thermal water. Uniejów also has three operating geothermal fountains producing hot water, which serves as an additional tourist attraction [53,54].

#### 4.2.5. Szaflary

The Podhalańskie thermal swimming pools in Szaflary, opened in spring 2008, use thermal water from the Mining Institute PEC Geotermia Podhalańska S.A. [55].

The Podhalańskie thermal swimming pools are a complex of all-year-round thermal pools, both outdoor and indoor, the total area of which is 970 m$^2$. Of the two indoor pools, one is equipped with a hydromassage facility and the other has a three-track slide. The outdoor pools too are equipped with hydromassage facilities and above a section of the pool a climbing net is hanging. The pool water is of a temperature between 30 and 38 °C and its therapeutical properties influence the muscular and osseous system, relieve the symptoms of skin diseases and contribute to the general feeling of well-being [55].

#### 4.2.6. Zakopane (the Aquapark in Zakopane)

The Aquapark "Zakopane", which was opened in December 2006, uses thermal water from its own mining institute exploiting the bore-hole intakes Zakopane IG-1 and Zakopane 2 [55]. The Aquapark's facilities include two leisure-swimming pools. In the indoor pool the surface is 384.5 m$^2$ and length 25 m, the water temperature is 28.5 °C and there are three swimming lanes as well as water jets in the leisure part of the pool. The pool depth varies from 130 to 150 cm. The outdoor swimming pool has a surface area of 390.8 m$^2$ and water temperature of 28.5 °C. There is a special shallow pool for the youngest visitors, which contains water with a temperature of 33 °C [56].

#### 4.2.7. Zakopane (Polana Szymoszkowa)

The thermal bath site at "Polana Szymoszkowa" ("Szymoszkowa Glade" in Polish) opened at the end of 2007 and started its commercial operation in April 2009. This site uses its own mining institute which exploits thermal water from a bore-hole Szymoszkowa GT-1. The geothermal bore-hole water in the swimming pool has a temperature of 30 °C and, due to a high content of minerals, has therapeutical properties and is recognised as a hydrogencarbonate–chloride–magnesium–sodium type of medical water [57].

**Table 5**
The number and types of heat pumps installed in Poland in 2009 [5].

| Pump type | Number [items] |
|---|---|
| Ground–water | 3750 |
| Air–water | 2950 |
| Water–water | 450 |
| Industrial | 95 |
| Gas | 60 |

## 5. Heat pumps in Poland

The heat pump market has been operating in Poland since 1995 when the first systems of this type were installed. Based on the world's experience in promoting and implementing heat pumps, the Polish Association for Heat Pumps (PAHP) was established in 2003 [58].

Currently, a few thousand heat pumps are installed every year; it is estimated that their numbers reached 10,000 in 2010. Among the systems that are installed, most belong to the following types: ground–water, air–water and water–water (the first part of the name indicates the lower source of heat) (Table 5). According to the predicted development of the heat pump market in Poland (by analogy to other countries), a yearly demand is estimated at 50,000–70,000 pumps [5].

As far as the vertical systems are concerned, which are also the most often used in Poland, there is no requirement for a construction or exploitation permit. There is only a requirement to notify the district head of the intention to implement such an installation for recording purposes. In case of open systems, where water is dumped to an aquifer or surface streams, it is essential to have geological work project performed (drilling a bore-hole). After drilling, hydrogeological documentation is drawn up to assess the exploitation resources of the underground water intake. The next step is to obtain a permission required under the Water Law Act in order to construct a water installation, a permit to exploit underground water as well as a permission to drain water off [59–61].

The cost of heating by using heat pumps is the lowest in Poland (18.06–35.41 PLN/GJ depending on the tariff) (Table 6). Prospective customers are still put off by the huge investment costs. The unit cost of installed heating power oscillates within a very wide range from 800 to 6000 PLN/kW and it is the highest for small installations in semi-houses. The bigger an installation is, the lower the unit cost [62].

### 5.1. Heat pumps in Poland – the analysis of surveys

In 2010 the authors sent about 400 surveys to companies producing and/or installing heat pumps as well as to individual customers. The authors received almost 150 replies (by letter or e-mail).

#### 5.1.1. Analysis of the surveys "Heat Pumps in Poland – Producers"

The polish companies that are currently producing and/or installing heat pumps in Poland have been operating for well over

**Table 6**
The cost of producing 1 GJ in Poland via various heating systems (own data based on Ref. [62]).

| Heat source | Unit [a] | Unit price of energy carrier PLN/[a] | Mean efficiency of a heating system [%] | Cost of 1 GJ of produced heat [PLN] |
|---|---|---|---|---|
| Electric current – tariff I | kW h | 0.51 | 98 | 144.56 |
| Electric current – tariff II | kW h | 0.26 | 98 | 73.70 |
| liquefied petroleum gas propane–butane | kg | 4.80 | 85 | 131.23 |
| Natural gas | $m^3$ | 1.62 | 85 | 59.08 |
| Fuel oil | kg | 3.26 | 80 | 107.80 |
| Hard coal | Mg | 705 | 60 | 40.06 |
| Heat pump – tariff I, COP = 4 | kW h | 0.51 | 400 | 35.41 |
| Heat pump – tariff II, COP = 4 | kW h | 0.26 | 400 | 18.06 |

1 USD = 2.78 PLN (20.06.2011).

a decade. Most of them were set up in the 1990s. As the interest in heat pumps in Poland increased, the companies extended their offer by providing/installing heat pumps. Many of the foreign competitors have been operating for 30–40 years [6].

Amongst the arguments the respondents pointed to as favouring the inclusion of heat pumps in their offer are:

- a chance for a company's quick development,
- a gradual increase in the interest in renewable energy sources in Poland,
- creating a full offer, starting with a source of heat and finishing with the final system,
- financial rewards,
- changes in legislation coming into force with the Act of July 2nd 2004 on Freedom of Economic Activity [63], which made it possible to extend economic activity,
- market demand for complex installation services: plumbing and electrical, the experience gained abroad.

The companies offer a wide range of heat pumps. One of the most commonly installed was a compression type pump: brine–water, water–water, water–air and air–air. The uptake of these types of pumps increases every year [6].

The companies tended not to disclose how many heat pumps they sold/installed during the previous year, explaining it was commercially sensitive information. The companies which did reveal these data sold or installed between 13 and 550 heat pumps in 2009, which meant an increase of 10–50% in comparison to the previous year.

The companies estimated the size of the heat pump market as follows:

- up to 2000 items per year – 10% respondents,
- 2000–4000 items per year – 10%,
- 4000–6000 items per year – 50%,
- above 6000 items per year – 20%.
- Not sure – 10%.

The respondents identified the following problems related to selling heat pumps in Poland:

- promotion of non-renewable energy sources and resulting ignorance of the state administration authorities, very complicated legal procedures,
- the lack of subsidies,
- limited knowledge of investors, designers and installers,
- high initial costs of heat pump installation,
- the lack of reliable installation companies,
- the lack of thorough information on heat pumps in the format accessible for an average end-user, most of the end-users are "educated" by promotional materials.

The respondents pointed out the following problems related to installing heat pumps:

- unclear legal requirements, the lack of a certification system for installers and systems, a lack of educational materials for installers, designers and users,
- many investors had problems obtaining a permission to carry out a probe (a vertical collector) of depth over 30 m – this makes installation more difficult,
- the lack of training events for installers, the lack of experienced staff, limited access to the knowledge and experience of other people.

The companies producing and/or installing heat pumps had the following plans for their development:

- improving the product (the heat pump),
- new products, staff training,
- carrying out research into optimisation of the heating and/or cooling process,
- extending a range of services, controlling "intelligent" houses [6].

*5.1.2. Analysis of the surveys "Heat Pumps in Poland – Customers"*

About 10% of respondents had heat pumps installed before 2000, 30% between 2000 and 2005, and the rest after 2005. These are the pumps produced by well-known companies, most often a compression type: brine–water, water–water, water–air. The owner of the longest operating pump installed it in 1996 [6]. The respondents had the installation costs that varied between 9000 and 7,000,000 PLN (on average 40,000–60,000 PLN). The costs varied depending on the number and type of pumps installed as well as the modernisation of the heating system.

About 15% of the respondents found it difficult to estimate the costs of heat pump installation – they realised the project themselves, using their own innovative ideas.

The investments were financed from the following sources:

- investors' own means,
- means from the Bank of Environmental Protection,
- bank loans,
- loans from the Domestic Housing Fund,
- preferential loans from the Voivodeships' Environmental Protection and Water Management Funds,
- means from the National Environmental Protection and Water Management Fund.

The respondents used the following types of lower heat sources: the ground (most often), lakes, water from the pipe-network, air. The upper heat sources included: radiators, floor heating systems, communal warm water from the network, pools and fan coil units. Half of the respondents stated that their pumps worked on their

own whilst in the remaining group, heat pumps worked together with a solar panel (most often) or a wood-fuelled furnace or gas boiler [7]. Almost all respondents were satisfied with their heat pumps, The owner of the longest operating heat pump stressed it had been working without breaking down for 15 years [7].

The majority of respondents did not indicate any problems related to heat pump installation; however, a few did highlight following difficulties:

- land slides in excavation,
- problems with installing a heat pump,
- the lack of a sufficient number of contractors,
- the lack of subsidies for the investment.

Similarly to the pump installation, there were only a few problems related to their operation. These included:

- high electric energy cost,
- a rapid increase in the price of materials,
- difficult access to the service,
- technical faults.

On average, the respondents did not know what the heat pump market looked like in Poland. They described it as "large" and "developmental". When precise figures were given, they were far lower than in the Survey for the Producers – at the level of 2000 heat pumps per year. One of the respondents stated that there were about 58,000 installed heat pumps in Poland.

About 20% of respondents were planning to install heat pumps in the future. The majority, however, thought it would not be necessary as the currently working heat pump fully met the heat demand. The respondents consistently emphasised the faultless operation of heat pumps and low maintenance needs. However, they stressed it was still a relatively expensive investment with a long waiting time for a financial return. They also warned other people who planned to purchase heat pumps against unreliable, inexperienced companies [7].

## 6. Future prospects for the development of geothermal energy in Poland

Fig. 14 shows where new sites using geothermal water are being built or are planned to be built. The work progress is various; some places are nearly completed (e.g. in Toruń), others have been granted a license to search for and recognise thermal waters and others are still within the land development phase [64–72]. According to the situation on January 1st 2011, 21 licenses to search for and recognise thermal water had been granted [67].

Uniejów is marked again on Fig. 14 because at present the first geothermal thermo-electric power plant in Poland is being built there. The installation is planned to open in the middle of 2012. It will be a hybrid thermal–electric power plant, combining geothermal energy and energy from biomass combustion. The cost of such thermal–electric power plant should be ca. 12 million PLN and the anticipated energy production shoud be 2.1 GWh [68].

Great progress has been made on the construction of a geothermal plant in Gostynin. In the area of Gostynin thermal water occurs at the temperature reaching 60 °C and with flow capacity of up to 200 $m^3$/h. The water temperature is sufficient to be used for heating purposes. The analysis of physico-chemical properties of the Lower Jurassic water occurring around Gostynin showed that, according to the assessment criteria of natural medical resources [69], there are grounds to class this type of water as specific mineral. This type of water is characterised by high mineralisation, temperature above 20 °C and having an iodine content exceeding 1 mg/$dm^3$. The local


**Fig. 14.** Planned and currently constructed sites using geothermal energy (own data based on Refs. [64–72]).

authorities of Gostynin prepared plans to set up the Multi-Regional Centre for Tourism, Leisure and Recreation. The Centre will provide medical services [69,70].

In the middle of 2011 a range of thermal swimming pools in the area of Podhale will be extended by the construction of a new centre in Białka Tatrzańska – "Thermal Swimming Pool Bania". An area of 10,000 $m^2$ will contain leisure pools for adults and children (with a specially designated zone for the youngest ones), a loud zone with water slides, a quiet zone (relaxation pools), a saunarium zone (consisting of five saunas, including an outdoor one "Bania") [71].

In the near future, the capital of Poland – Warsaw – will also benefit from geothermal heat. In the nearby town of Piaseczno water from the bore-hole Piaseczno GT-1, at a temperature of 50 °C, will be used for heating swimming pools and for the underfloor heating systems of the Warsaw Thermal Pools. It is planned to use geothermal water in stepped falls as cooled down water from the Warsaw Thermal Pools is to be directed to the Geothermal Plant, where in heat exchangers it will give up its heat to the water circulating in the network. The network water will become the lower heat source for a heat pump and its temperature will increase to 59 °C. The returning network water of temperature of 36 °C will be cooled down to 20 °C and then directed to a pressing well [72].

It is planned to use heat pumps for recovering waste heat from industrial factories and power plants in Poland. For example, in the area of Konin there are lakes which receive hot water from brown coal power plants, due to which they never freeze and could successfully be used as a lower heat source for heat pumps. The Pątnowskie Lake in Konin hosts the only winter sailing competition in Poland known as the Barbórka Winter Regatta [73].

In Poland, where the energy sector relies heavily on hard and brown coal, there is a need to drain water from deep mines (hard coal) and strip mines (brown coal) [74]. The temperature of mine water remains virtually constant throughout the year ranging between 11 and 19 °C. For example, a study carried out by the Polish Academy of Sciences [75] suggests potential uses of mine water for the hard coal mine piast (KWK Piast).

An interest in geothermal energy of low enthalpy has been growing in Poland with every year. In the coming years heat pumps

will be installed in housing and office buildings as well as in public use buildings (mostly newly built) [76].

## 7. Summary

Poland features large resources of geothermal energy that could be directly used, especially in a widely understood heating sector (geothermal heat plants, heat pumps).

However, despite a promising resource base and a great interest among prospective investors and customers, the development of geothermal energy in Poland is limited by the following barriers:

- legal regulations and financial conditions that are adverse to investment,
- long and complicated legal and administrative procedures (which result in delaying the release of means, loss of their value and discouraging investors),
- the lack of sufficient incentives and economic instruments,
- the lack of "green certificates" for geothermal heat,
- high investment costs, and
- low awareness of geothermal energy in the society.

Poland is facing a great challenge to overcome the above obstacles. The development of geothermal power [77], solar power [78], wind power [79], hydro-power [80] and bioenergy [81] engineering will facilitate Poland's energy independence and ultimately lower the cost of heat and electric power for customers.

## Acknowledgements

We would like to thank Geotermia Podhalańska S.A., Geotermia Pyrzyce Sp. z o.o. and Geotermia Uniejów for the opportunity to visit the geothermal plants and materials provided.

We would like to thank participants of surveys, who provided us the information about production and processing of geoenergy in Poland.

## References

[1] Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, OJ L283/33, 27.10.2010.
[2] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC OJ L 140, 5.6.2009.
[3] Energy from Renewable Sources in 2006, Central Statistical Office–Department of Production, Ministry of Economy, Energy Department Warsaw 2007, http://www.stat.gov.pl/gus/5840_5010_PLK_HTML.htm (accessed on 05.03.11).
[4] Energy from Renewable Sources in 2009, Central Statistical Office–Department of Production, Ministry of Economy, Energy Department, Warsaw 2010, http://www.stat.gov.pl/gus/5840_3680_PLK_HTML.htm (accessed on 05.03.11).
[5] Grochal BJ. The heat pump market in Poland, seminar materials: Installation and Heating Industry in Poland – 2009 and What's Next? International Installation Fair – INSTALACJE 2010, 26-29.04.2010 Poznań [in Polish].
[6] Survey Heat Pumps in Poland – Producers (carried out by the authors), Toruń, 2010.
[7] Survey Heat Pumps in Poland – Customers (carried out by the authors), Toruń, 2010.
[8] Igliński B, Kujawski W, Buczkowski R, Cichosz M. Renewable energy in Kujawsko-Pomorskie Voivodeship (Poland). Renewable and Sustainable Energy Reviews 2010;14:1336–41.
[9] Igliński B, Iglińska A, Kujawski W, Buczkowski R, Cichosz M. Bioenergy in Poland. Renewable and Sustainable Energy Reviews 2011;15:2999–3007.
[10] Hurter S, Schellschmidt R. Atlas of geothermal resources in Europe. Geothermics 2003;32:779–87.
[11] Kępińska B. Current state and prospects of geothermal energy implementation in Poland. Applied Energy 2003;74:43–51.
[12] Górecki W, editor. Atlas of geothermal resources of mesozoic formations in the polish lowlands. Kraków: University of Science and Technology; 2006.
[13] Górecki W, editor. Atlas of geothermal resources of paleozoic formations in the polish lowlands. Kraków: University of Science and Technology; 2006.
[14] Bujakowski W. The use of geothermal water in climatic, recreational, balneological, and heating contexts, conference materials, Warsaw 2009, The VI Forum of System Operators and Energy and Fuels Consumers: The Energy Security and New Directions of Prodcing and Using Energy in Warsaw available on: www.energia365.pl/dokumenty/W.Bujakowski.pdf (accessed on 15.03.11) [in Polish].
[15] Szewczyk J, Gientka D. Terrestrial heat flow in Poland – a new approach. Geological Quarterly 2009;53(1):125–40.
[16] Długosz P. Podhale (South Poland) geothermal district heating system. Geothermics 2003;32:527–33.
[17] Igliński B, Buczkowski R, Cichosz M, Piechota G. Geoenergetics technologies. Toruń: Nicolaus Copernicus University; 2010 [in Polish].
[18] Kępińska B. The Podhale geothermal system and heating project – a review of main issues. In: Kępińska B, Popovski K, editors. International geothermal days, POLAND 2004. Cracow: Instytut Gospodarki Surowcami Mineralnymi i Energią PAN; 2004. p. 243–58 [in Polish].
[19] Sokołowski J. The geothermal resources of Poland and their potential use in environmental protection. Technology of Geological Exploration Geosynoptics and Geothermics 1993;5–6:67–80 [in Polish].
[20] Wartak W, Wróbel A, Ignacok W. PEC Geotermia Podhalańska S.A. – geothermal heat plant in Podhale: experience, selected aspects of work, prospects. Technology of Geological Exploration 2007;27(2):125–31 [in Polish].
[21] Ślimak C. PEC Geotermia Podhalańska S.A., Zakopane, May 2010, materials available on: http://e-bmp.pl/Image/Czeslaw%20Slimak%282%29.pdf (accessed on 15.04.11) [in Polish].
[22] Kępińska B. The thermic and hydrothermal conditions of the Podhale geothermal system. Cracow: Wydawnictwo Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN; 2006 [in Polish].
[23] Ślimak C, Wartak W. PEC Geotermia Podhalańska S.A. Experiences, the current state, development prospects. Technology of Geological Exploration 2009;28(2):123–32 [in Polish].
[24] Balcer M. The geothermal plant in Mszczonòw – selected aspects of work, experiences. Technology of Geological Exploration 2007;47(2):113–4 [in Polish].
[25] Kulik S. The Geothermal Heat Plant in Pyrzyce: experiences, selected aspects of work, prospects. Technology of Geological Exploration, Geothermics, Balanced Development 2007;240:63–7 [in Polish].
[26] http://geotermia.inet.pl (accessed on 14.03.11).
[27] Biernat H, Kulik S, Noga B. The geothermal installation in Pyrzyce as an example of pure and renewable energy production in heating industry as well as use of thermal water in balneology and recreation. Geological Review 2010;58(8):712–6 [in Polish].
[28] http://www.geotermia-uniejow.pl (accessed on 12.05.11).
[29] Kurpik J. Geotermia Uniejów as an example of use of thermal waters. Technology of Geological Exploration 2007;27(2):119–20 [in Polish].
[30] Hanausek P, Klonowicz P, Krysiński J. A concept of a hybrid geothermal plant in Uniejów. Geological Review 2009;57(8):654–5 [in Polish].
[31] Saysse-Tobiczyk K. The polish spas: an illustrated guide to spas, climate resorts, sea resorts holiday and leisure sites. Warsaw: Wydawnictwo Polskiego Archiwum Krajoznawczego i Fotografii Dokumentarnej; 1947 [in Polish].
[32] Kępińska B, Łowczowska A. Geothermal waters in medicine recreation and tourism. Cracow: Wydawnictwo Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN; 2002 [in Polish].
[33] Latour T. The current state and the further possibilities of the use of thermal waters for medical and preventive purposes as well as for recreation. Technology of Geological Exploration 2007;46(2):63–7 [in Polish].
[34] Iwanowska-Jeske D, editor. The spa of Ciechocinek. Warsaw: Wydawnictwo Sport i Turystyka; 1983 [in Polish].
[35] Kubiak S. Ciechocinek: the history of the spa. Włocławek: LEG Oficyna Wydawnicza Włocławskiego Towarzystwa Naukowego; 2001 [in Polish].
[36] Krawiec A. The thermal waters in Ciechocinek spa. Technology of Geological Exploration 2009;48(2):73–7 [in Polish].
[37] Papaj M. Cieplice-Zdrój: the spa district of Jelenia Góra: an illustrated guide with maps: the spa's attractions, local trips spa therapy. Jelenia Góra: Wydawnictwo Turystyczne Plan; 2008 [in Polish].
[38] Dowgiało J, Leśniak PM. Selected results of hydrogeological observations of stationary thermal waters in Cieplice-Zdrój. Geological Bulletin 1976;21:265–77 [in Polish].
[39] Derkowska M, Sawicki J. Physical properties of Cieplice-Zdrój medical waters – variability, interdependence and influence of meteorological conditions. The Scientific Dissertations of the Mining Institute of the Wrocław University of Technology 2002;102:27–37 [in Polish].
[40] Dowgiałło J. The Thermal waters of the Sudety mountains. Acta Geologica Polonica 1976;26(4):617–40 [in Polish].
[41] Nowacki R. Duszniki Zdrój. Opole: Oficyna Wydawnicza Politechniki Opolskiej; 2005 [in Polish].
[42] Fistek J. The use of thermal waters in the Sudety spas of Poland. Technology of Geological Exploration 2008;47(1–2):3–8 [in Polish].
[43] Michalak J. Iwonicz Zdrój and its surroundings: Iwonicz Zdrój 1837–1987: 150 years of the spa establishment. Rzeszów: Krajowa Agencja Wydawnicza; 1987 [in Polish].
[44] http://www.iwonicz-zdroj.pl (accessed on 28.04.11).
[45] http://www.konstancin.com (accessed on 29.04.11).
[46] Ciężkowski W. Lądek Zdrój. Wrocław: Dolnośląskie Wydawnictwo Edukacyjne; 2008 [in Polish].
[47] Sosna W. Ustroń, Wisła Szczyrk and the surroundings: a guide. Warsaw: Wydawnictwo Sport i Turystyka; 1977 [in Polish].
[48] Promotional materials Thermal Swimming Pools in Bukowina Tatrzańska, Bukowina Tatrzańska, July 2010 [in Polish].

[49] http://www.termabukowina.pl (accesssed on 15.05.11).
[50] http://www.geotermiagrudziadz.pl (accessed on 17.05.11).
[51] Krawiec A. The results of isotope and chemical investigations of medical waters in the area of Grudziądz. In: Fl'akova R, Zenisova Z, editors. XI International Science Conference Hydrogeochemia. 2007. p. pp49–55 [in Polish].
[52] http://www.termy-mszczonow.eu (accessed on 30.05.11).
[53] http://www.uniejow.pl (accessed on 22.05.11).
[54] http://www.termyuniejow.pl (accessed on 22.05.11).
[55] http://www.termypodhalanskie.pl/pl (accessed on 30.05.11).
[56] http://www.aquapark.zakopane.pl (accessed on 24.05.11).
[57] http://szymoszkowa.pl (accessed on 15.05.11).
[58] http://www.pompaciepla.org.pl (accessed on 11.04.11).
[59] Smuczyńska M. Ground, water or air? The optimum choice of a heat pump (1). Installer's Magazine 2010;7–8(143–144):40–2 [in Polish].
[60] Smuczyńska M. Ground, water or air? The optimum choice of a heat pump (2). Installer's Magazine 2010;9(145):32–4 [in Polish].
[61] Smuczyńska M. Ground, water or air? The optimum choice of a heat pump (3). Installer's Magazine 2010;11(147):33–5 [in Polish].
[62] Kapuściński J, Rodzoch A. Low temperature geothermics in Poland and the world. Warsaw: Wydawnictwo Borgis; 2010 [in Polish].
[63] The Act of July 2nd 2004 on Freedom of Economic Activity. Journal of Law 2004 no. 173, item 1807, http://isip.sejm.gov.pl/DetailsServlet?id=WDU20041731807 (accessed on 27.04.11).
[64] Ciężkowski W, Chowaniec J, Górecki W, Krawiec A, Rajchel L, Zuber A. Mineral and thermal waters of Poland. Geological Overview 2010;58(9/1):762–73 [in Polish].
[65] Barbacki A. Classification of geothermal resources in Poland by exergy analysis – Comparative study. Renewable and Sustainable Energy Reviews 2012;16:123–8.
[66] Majorowicz J, Šafanda J. Heat flow variation with depth in Poland: evidence from equilibrium temperature logs in 2.9-km-deep well Torun-1. International Journal of Earth Science 2008;97:307–15.
[67] A list of licences for searching for and recognising thermal waters, brines and medical minerals in Poland. The current state on January 1st 2011, http://www.mos.gov.pl/g2/big/2011_01/a3fa150c9b21c14fe700b38969addebf.pdf. (accessed on 05.05.11).
[68] http://finanse.wp.pl/kat, 9231,title,W-Uniejowie-powstanie-elektrocieplownia-hybrydowa,wid,13020101,wiadomosc.html?ticaid=1bed1. (accessed on 06.05.11).
[69] Tomaszewska B, Barbacki AP. The initial recognition of hydrogeochemical properties of thermal waters in the area of Gostynin. Technology of Geological Exploration 2008;47(1–2):59–67 [in Polish].
[70] http://www.terazgostynin.pl/news.php?readmore=280. (accessed on 22.06.11).
[71] http://www.termabania.pl. (accessed on 04.05.11).
[72] http://www.termoglob.com/Termoglob_koncepcja.pdf. (accessed on 07.04.11).
[73] http://www.enrgklub.konin.lm.pl/zrb.html. (accessed on 12.04.11).
[74] Hall A, Ashley Scott J, Shang H. Geothermal energy from underground mines. Renwable and Sustainable Energy Reviews 2011;15:916–24.
[75] Polish Academy of Sciences. The use of mine waters' energy to meet heating demand of a mine bath in the Hard-Coal Mine Piast; http://www.silesia-region.pl/oze/sc_kwk_piast.pdf (accessed on 22.05.11) [in Polish].
[76] Śliwa T, Kotyza J. Application of existing wells as ground heat source for heat pomps in Poland. Applied Energy 2003;74:3–8.
[77] Kępińska B. Geothermal energy country update report from Poland, 2005-2009, Proceedings World Geothermal Congress 2010, Bali, Indonesia, April 25-29, 2010, paper No. 0108, pp. 8.
[78] Pietruszko SM. Photovoltaics in Poland. Applied Energy 2003;74:169–75.
[79] Michalak P, Zimny J. Wind energy development in the world, Europe and Poland from 1995 to 2009; current status and future perspectives. Renewable and Sustainable Energy Reviews 2011;15:2330–41.
[80] http://www.tew.pl/. (accessed on 12.04.11).
[81] Budzianowski MW. Sustainable biogas energy in Poland: Prospects and challenges. Renewable and Sustainable Energy Reviews 2012;16:342–9.